MODIS

Terra Instantaneous Photosynthetically Available Radiation IPAR, and Absorbed Radiation by Phytoplankton ARP (MOD22)

Data Quality Summary

Last updated: February 15, 2003

Investigation:	MODIS
Data Product:	IPAR and ARP (MOD22)
Data Set:	Terra
Data Set Version:	Collection 4 version 4.2 reprocessed
Dates:	November 1, 2000 through March 2002
Status:	Validated

Nature of the Product

Chlorophyll-*a* concentration is the most widely used product derived from ocean color remote sensing data. The first such measurements were made by the Coastal Zone Color Scanner (CZCS) operating between 1978 and 1986. With improved spectral and radiometric resolution, the Sea-viewing Wide Field-of-View (SeaWiFS) sensor began producing global maps of chlorophyll-*a* concentration in September 1997. Neither CZCS nor SeaWiFS, however, had a band near 685 nm where chlorophyll *a* fluoresces, so measurements of one direct response (fluorescence) of chlorophyll *a* to absorbed radiation by phytoplankton (ARP) was not available to scientists using those sensors. The other direct responses are heating and carbon-fixation through photosynthesis. Since these are competitive processes (e.g. Butler 1978), knowledge of the fraction of light absorbed by phytoplankton that results in fluorescence (fluorescence efficiency) reduces the uncertainty about the amount of light utilized by the photosynthetic process under a variety of environmental conditions (see Esaias et al. 1998 overview and ATBD-MOD-22; *http://modis.gsfc.nasa.gov/data/atbd/atbd_mod22.pdf* regarding fluorescence line height FLH).

Since MODIS has a sensitive enough band at 678 nm to respond to chlorophyll fluorescence (Esaias et al. 1998), estimates of fluorescence efficiency are dependent upon the absorbed quanta by phytoplankton in the surface layer where fluorescent light can be observed by MODIS. This in turn is dependent upon IPAR, the photo synthetically available radiation (quanta) entering the sea surface at the instant that MODIS is observing the fluorescent signal. The spectral absorption coefficients of phytoplankton, $a_{ph}(\lambda)$ and the spectral total absorption coefficients $a(\lambda)$ (MOD36) are derived using the model discussed in *http://modis.gsfc.nasa.gov/data/atbd/atbd_mod19.pdf* and Carder et al. (1999). The spectral total absorption coefficients are needed to calculate the light field with depth (e.g. Liu et al. 2002).

The methods used to calculate the IPAR and ARP products are summarized below. The Chlorophyll-a concentration product has one parameter (chlor_a_3, parameter 27), hereinafter referred to as [chl a]. IPAR and ARP products consist of two parameters: IPAR (ipar, parameter 28), and ARP (arp, parameter 29). The Dissolved Organic Matter Absorption product has one parameter: dissolved organic matter absorption at 400nm (absorp_coef_gelb, parameter 30), hereinafter referred to as $a_g(400)$. The Total Absorption products consist of six parameters: phytoplankton absorption at 675nm (chlor_absorb, parameter 31), hereinafter referred to as $a_{ph}(675)$, total absorption at 412nm (tot_absorb_412, parameter 32), total absorption at 412nm (tot_absorb_443, parameter 33), total absorption at 488nm (tot_absorb_488, parameter 34), total absorption at 531nm (tot_absorb_531, parameter 35), and total absorption at 551nm (tot_absorb_551, parameter 36), hereinafter referred to as $a(412)$, $a(443)$, $a(488)$, $a(531)$, and $a(551)$, respectively.

The semi-analytical, bio-optical model of remote-sensing reflectance (e.g. normalized water-leaving radiance) developed by Carder et al. (1999) and Carder et al. (accepted) provides the basis for the MODIS algorithm for the concentration of chlorophyll *a* as well as for calculations of absorbed radiation by phytoplankton (ARP). The latter quantity is utilized by the MODIS chlorophyll fluorescence-yield algorithm (Abbott, ATBD-MOD-22) to form a parameter indicative of the physiological state of phytoplankton, the quantum yield of fluorescence.

The algorithm is developed such that four quantities are simultaneously determined: chl *a*, absorption by gelbstoff (dissolved blue-absorbing organic matter) at 400nm, absorption coefficient of phytoplankton (expressed at 675nm), and ARP. With these variables, the total absorption coefficients for the visible region can be deduced through use of algorithm parameters. ARP also depends upon the instantaneous flux of photons per wavelength interval just beneath the sea surface (Gregg and Carder 1990), which is calculated as part of the instantaneous photosynthetically available radiation algorithm (IPAR). ARP is an expression of the quanta absorbed by phytoplankton in the top 3m of the water column, the interval from which more than 90% of the upwelling fluorescence photons, which are seen by the sensor, originate.

Chlorophyll_a pigment concentrations for Case 2 waters (Chlor_a_3; MOD21) are defined as values retrieved in the presence of absorption by colored dissolved organic matter (CDOM). This separation is achieved by using the spectral differences between absorption curves for phytoplankton, $a_{ph}(\lambda)$, and absorption curves for CDOM, a.k.a. gelbstoff, $a_g(\lambda)$. In reality, $a_g(\lambda)$ also includes absorption due to particulate detritus, which has a similar spectral shape. Together they are termed the Dissolved Organic Matter Absorption product, having one parameter: dissolved organic matter absorption at 400nm (absorp_coef_gelb, parameter 30). The strategy for achieving this separation is discussed by Carder et al. (1999) and in the updated version of the algorithm theoretical basis document ATBD-MOD-19.

Absorption by gelbstoff, detritus, and water molecules remove light from the water column, converting it into heat. Absorption by phytoplankton also removes light from the water column, but in addition to into producing heat and photosynthesis, the absorption also produces fluorescence with a yield typically less than about 5% (e.g. Kiefer 1973). All of the absorption products discussed above attenuate the light reaching and absorbed by phytoplankton as a function of depth. Therefore assessing the accuracy of MODIS-derived ARP values is not directly achievable since no database of all of these properties plus IPAR is available for testing algorithm performance.

Data Accuracies

Indirect evaluations of ARP can be made, however. Combining the Fluorescence Line Height with ARP produces Fluorescence Efficiency η_{FL} (ATBD-MOD-22). Values from 0.25% to 5% are expected of this property except for senescent blooms such as red tides, where values of 10% have been observed (Kiefer 1973; Gordon 1979; Carder et al. 1985). We will show η_{FL} fields from MODIS fall in this expected range.

Evaluations of ARP accuracy based upon ship radiometry of ARP components such as $a_{ph}(\lambda)$ (~30%) and $a_g(\lambda)$ (~40%) have been performed (Carder et al. 1999). Summing the constituent absorption coefficients together including the coefficient for water absorption, $a_w(\lambda)$(Pope and Fry 1997), provides the total absorption coefficient, $a(\lambda)$. For extremely clear waters using field radiances, Ivey et al. (2002) derived a(440) values using the MODIS semi-analytic algorithm (ATBD-MOD-19) that were within 15% (+/- 0.004 m^{-1}) of the average of 4 other methods. Overestimation of $a_{ph}(\lambda)$ is compensated by underestimation of $a_g(\lambda)$ since the model used (Carder et al. 1999) spectrally partitions the constituent absorption coefficients from total absorption. Thus total absorption accuracies are more exact than constituent estimates, since total absorption has a higher signal-to-noise ratio. Lee et al. (2002) found using numerical data that for retrieval accuracies of 18% for $a_{ph}(440)$ and $a_g(440)$, the retrieval accuracy for a(440) was 14%, since $a_w(\lambda)$ is known to a high degree of accuracy (Pope and Fry 1997). Details of component accuracy can be found in Carder et al. (1999) and ATBD-MOD-20 (http://modis.gsfc.nasa.gov/data/atbd/atbd_mod20.pdf).

Attenuating the light field to the shallow depths (e.g. < 5 m) from whence most chlorophyll *a* fluorescence emanates is straightforward. Light is attenuated as a function dominated by $a(\lambda)/\mu_d$, where μ_d is the down-welling average cosign just beneath the sea surface. The light field near the surface can be determined to within a few percent (e.g. Liu, Carder et al. 2002). Even with the near-surface simplifications for μ_d (Kirk 1994) in ATBD-MOD-20, errors in calculating PAR(λ, z) will be less than 10%.

If we attribute accuracies of ~7% to IPAR (ATBD-MOD-20), ~ 30% to $a_{ph}(\lambda)$ (Carder et al. 1999; ATBD-MOD-19), and 10% for PAR for the shallow depths from whence water-leaving fluorescence originates, then summing the squares of these error sources provides an **error estimate for ARP of root[$0.07^2 + 0.30^2 + 0.10^2$] = 33%**.

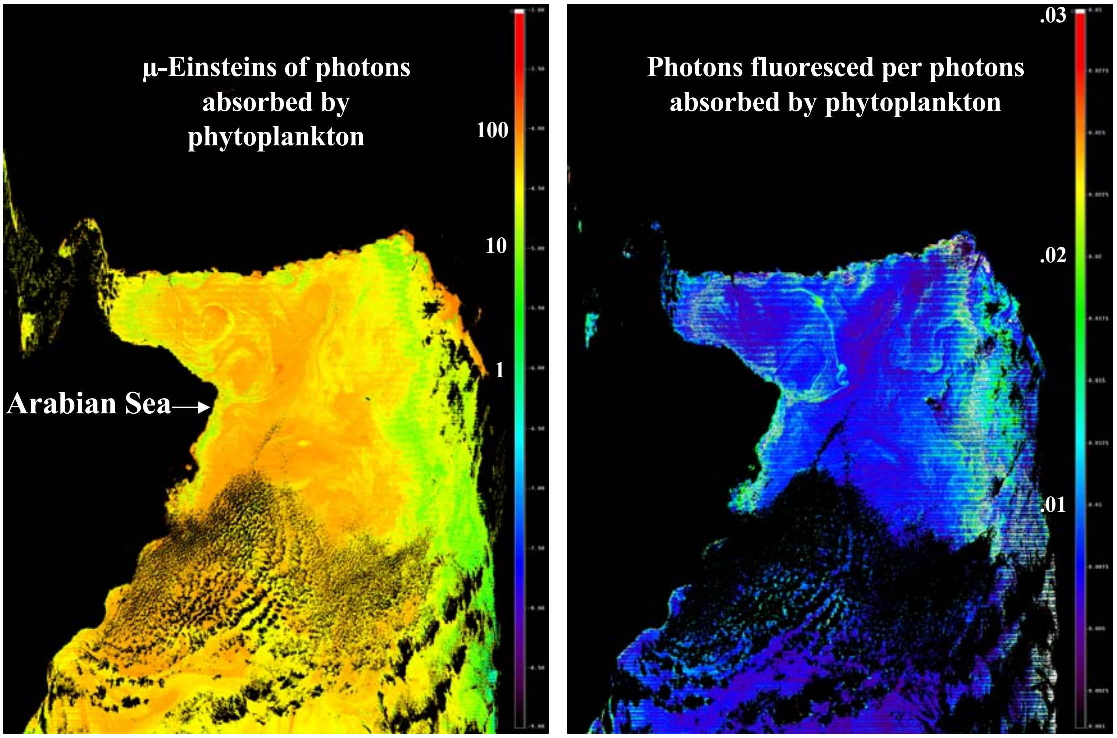

Figure 1. ARP and fluorescence yield for the Arabian Sea.

Fluorescence yield depends upon the quanta ratio FLH/ARP, and it ranges up to 10%. It is typically 5% or less, and its accuracy is going to be dominated by the accuracy of FLH, especially for clear waters (see ATB-MOD-22). An uncertainty in ARP of say 35% with "perfect knowledge" of FLH would provide fluorescence yield values ranging from 1.3% to 2.7% given a "true" fluorescence yield value of 2%. Since the errors due to ARP are not limited by signal-to-noise ratios for most of the ocean, they are going to be not random, but systematic or smoothly varying, providing scenes that have gradients that are clearly evident and consistent with fields of Chlor_a_3. Error effects of ARP on fluorescence yield then are not expected to degrade gradient features associated with circulation and pigment patchiness.

MODIS Terra images of ARP and fluorescence yield (Figure 1) can be compared to the chlorophyll fields of Chlor_a_2 and Chor_a_3 (Figure 2) and of absorption due to gelbstoff (Figure 3). Note that along the eastern boundary, ARP and fluorescence yield are minimal and maximal, respectively, for this scene. This corresponds to a region where gelbstoff is high, which attenuates the light available for absorption by phytoplankton and thus ARP. The gelbstoff may also be reducing photo-inhibition effects that can occur on sunny days since the region of lowest fluorescence efficiency (<0.75%) corresponds to a region where gelbstoff also is lowest (<0.1 m^{-1}).

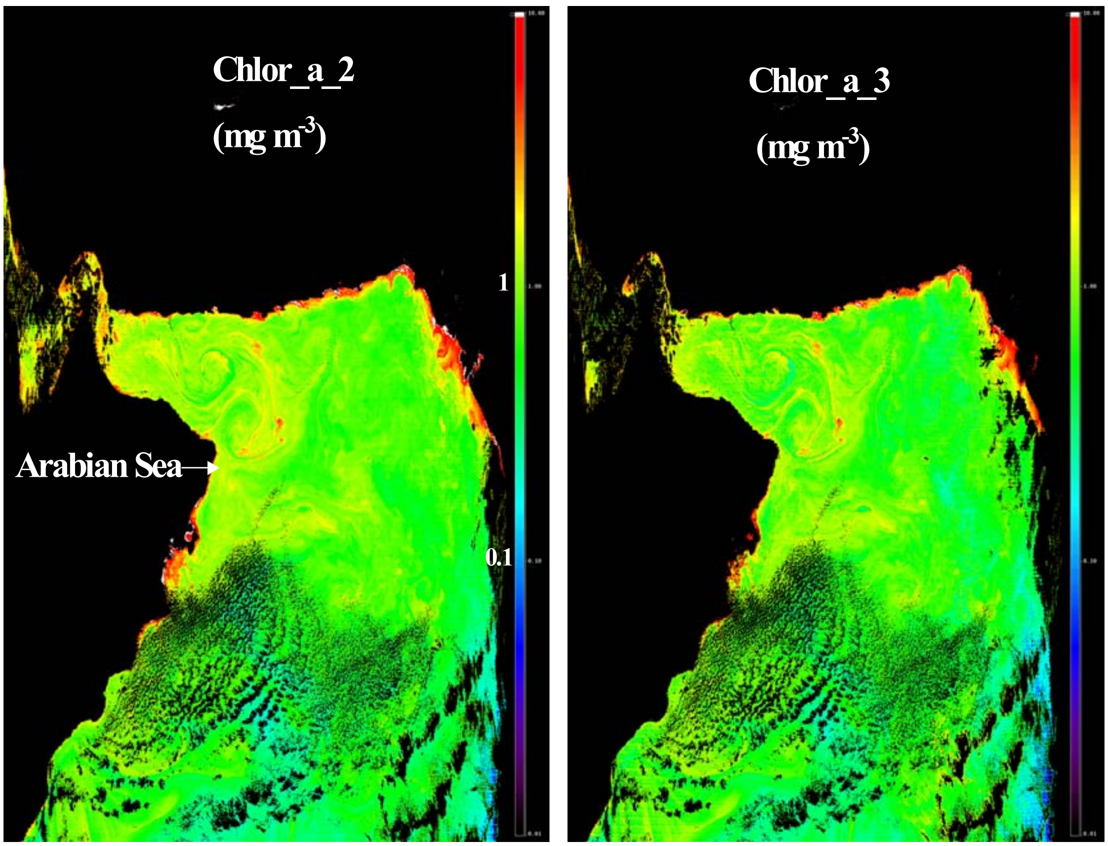

Figure 2. Chlor_a_2 and Chlor_a_3 distributions (mg m^{-3}) for the Arabian Sea.

The fact that fluorescence yield patterns are consistent with other biogeochemical distributions is indicative of the fact that errors in ARP values do not seriously limit the interpretation of scenes in terms of possible physiological explanations for the variations. Since this is the primary purpose for fluorescence yield, which is the reason for generating ARP and IPAR values in the first place, the 7% error attributed to IPAR and the 35% error attributed to ARP do not mask the utility of fluorescence yield, at least for values between 0.5% and 3% for the Arabian Sea. Consistent curvilinear patterns with gradients as low as 0.2% around 0.8% are apparent, suggesting that the relative errors in fluorescence efficiency are less than 25%. **Cautions When Using Data**

Only data of Quality Level 0 or 0 and 1 should be used in the data match-up comparisons (e.g. Carder et al. accepted), meaning that screening has been employed for sun glint, shallow water (<30 m), and extreme-angle pixels. More relaxed conditions for data of Quality Level 1 permits shallower water. Definitions of Quality Levels can be found at http://modis-ocean.gsfc.nasa.gov/qa/L2QLflags.V4.html. In addition to the exceptions

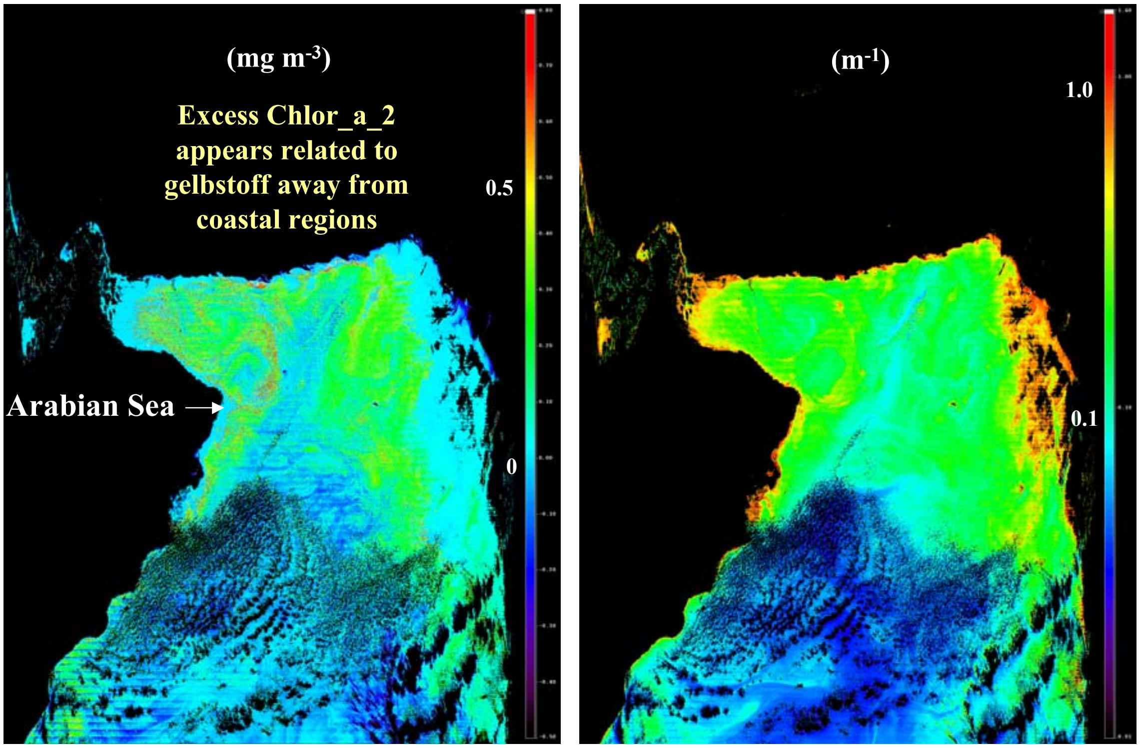

Figure 3. Chlor_a_2 – Chlor_a_3 and absorption by colored dissolved organic matter (gelbstoff) at 400 nm for the Arabian Sea.

listed above, the user should be cautioned regarding use of Collection 4 data at the scene edges when obvious striping is occurring. Avoiding the 100 pixels or so along each swath edge reduces this effect somewhat, but the degree of the problem varies from scene to scene as a result in part of unresolved polarization effects in Collection 4 data (see http://modis-ocean.gsfc.nasa.gov/qual.html/dataqualsum/nLw_qualsum.V4.pdf).

Anticipated Revisions

Recent improvements in Terra calibration knowledge based upon MODIS Aqua performance and calibration history regarding polarization effects suggest that the striping problem of Terra for Bands 8 and 9 can be significantly reduced and will be much less apparent for Aqua and for Terra after the next reprocessing (R. Evans, personal communication; http://modis-ocean.gsfc.nasa.gov/whatsnew.html). This should significantly improve accuracy especially near scene edges sun glint for Chlor_a_3 retrievals for both spacecraft.

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